UDC 621.391.812.63
621.391.812.8

1969
THE QUEEN'S AWARD
TO INDUSTRY

RESEARCH DEPARTMENT REPORT

Low-frequency sky-wave propagation to distances of about 2000 km

No. 1971/8

Research Department, Engineering Division
THE BRITISH BROADCASTING CORPORATION

RESEARCH DEPARTMENT

LOW-FREQUENCY SKY-WAVE PROPAGATION TO DISTANCES OF ABOUT 2000 KM

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It uses SI units in accordance with B.S. document PD 5686

Work covered by this report was undertaken by the BBC Research Department for the BBC and the ITA

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(RA-74)

Research Department Report No. 1971/8

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March 1971

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LOW-FREQUENCY SKY-WAVE PROPAGATION TO DISTANCES OF ABOUT 2000 km

Summary

Measurements of l.f. transmissions, made by the EBU over paths of about 2000 km, have been re-analysed to determine how the strength of the sky wave varies at sunset and sunrise. The results show that the field strength at these times is about 20 dB lower than the field strength late at night. Six hours after sunset the field strength is approximately the same as the annual median value for midnight, given by the CCIR propagation curves.

1. Introduction

In Europe the 15 channels in the l.f. band are shared between about 30 transmitters. If the frequencies are re-assigned at a future planning conference it should be possible to allocate most of the channels to pairs of transmitters separated by about 2000 km. Although co-channel interference would be minimised, some interference would occur, especially at night. The purpose of this report is to provide data which will enable interference levels to be assessed.

The EBU/CCIR propagation curves[1,2] show annual median field strengths for stated times throughout the night. Although the curves are reasonably accurate around midnight, they give no indication of the way in which the sky-wave field strength increases at sunset and decreases at sunrise. Knowledge of the variations which occur at these times is important because it enables the period during which a service is reasonably free from interference to be determined.

In order to study these variations, some of the l.f. measurements organised by the EBU have been re-analysed, and the results are described here. The new analysis was confined to paths of about 2000 km, the measurements used being those made of the Allouis transmitter (164 kHz) at Enköping, Sweden (1680 km), Helsinki, Finland (2060 km) and Lulea, Sweden (2350 km).

2. Analysis of measurements

During the 1959 measuring campaign of the EBU, continuous field strength recordings of Allouis were made between 1430 and 0530 GMT at weekly or fortnightly intervals. Each recording was divided into 30 half-hour periods and the median field strength found for each period. In the original analysis, all the median values measured in each half-hour period during a complete year were grouped together. This resulted in a large dispersion of the median values at the beginning and end of the 15-hour period, because both day and night conditions occur at these times during the year.

In the present analysis, the half-hour medians were plotted against the times after sunset (or before sunrise) at which the measurements were made. Sunset and sunrise times at the ground below the ionospheric reflection point for the path, rather than in the ionosphere itself, were used as references because they are easily derived from tables. Although the sun sets about 40 minutes later in the E layer, its rays are considerably weakened by their passage through the Earth's atmosphere after ground sunset or before ground sunrise. Consequently there is some justification for adopting ground sunset and sunrise times as references, and they are used throughout this report.

The lower ionosphere decays steadily during the night until about two hours before sunrise.[3] The measurements were therefore divided into two groups: those made during the night until two hours before sunrise, which were referred to sunset time, and those made later, which were referred to sunrise time. Quasi-maximum, median and quasi-minimum* values were determined for each half-hour period relative to sunset and sunrise, corrections being made for any change of transmitter power which occurred.

* These are the values exceeded by the half-hourly medians on 10%, 50% and 90% respectively of the nights on which measurements were made.

2.1. Allouis-Enköping path (1680 km)

Measurements were made at weekly intervals during 1959; alternate measurements were used for the present analysis. Fig. 1 shows that the median field strength rises rapidly at sunset and falls more rapidly at sunrise. Also shown in Fig. 1 is the theoretical ground-wave field strength; the tendency of the median field strengths to approach the ground-wave value outside the hours of darkness should be noted. Fig. 1 may be compared with Fig. 8 of Reference 2, which shows the earlier analysis of the same data. It will be seen that the use of sunset and sunrise times as references considerably reduces the dispersion of the measurements, indicated in Fig. 1 by the separation of the quasi-maximum and quasi-minimum values.

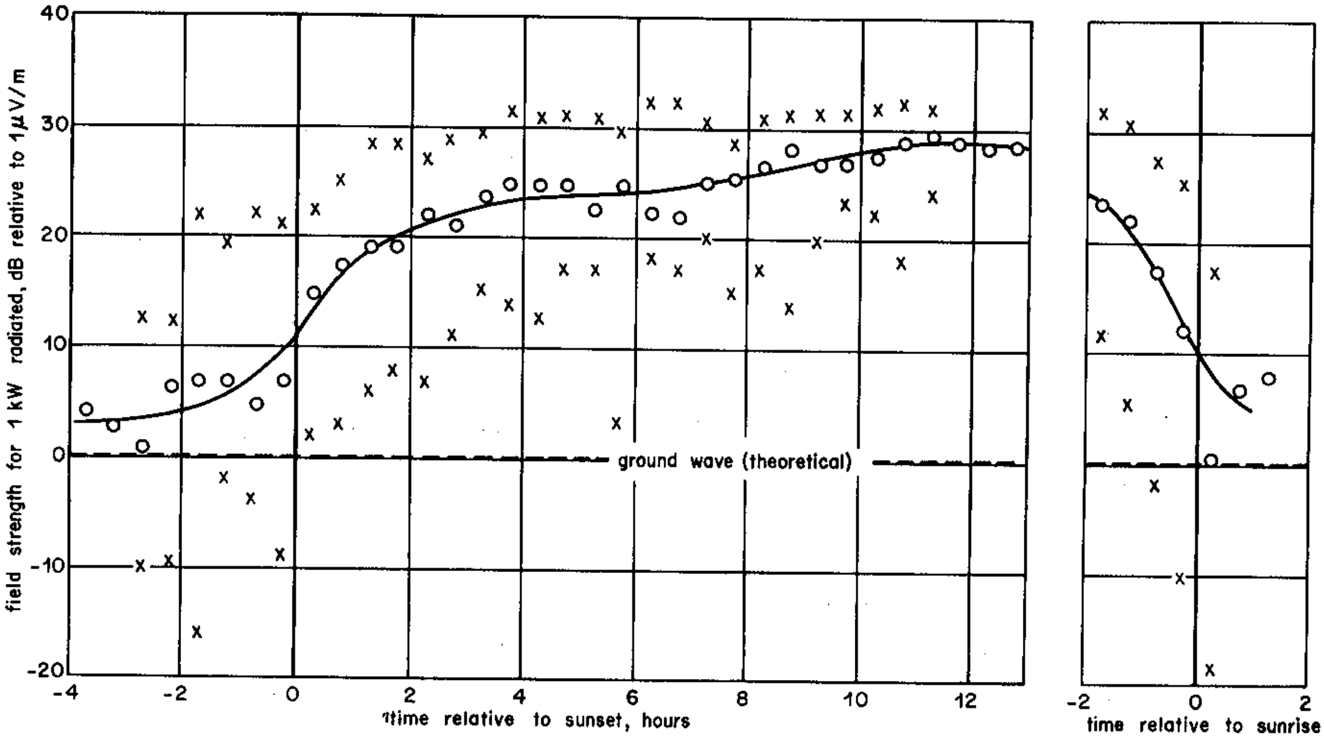

Fig. 1 - Allouis — Enköping measurements, 1959

O Medians X Quasi-maxima and quasi-minima

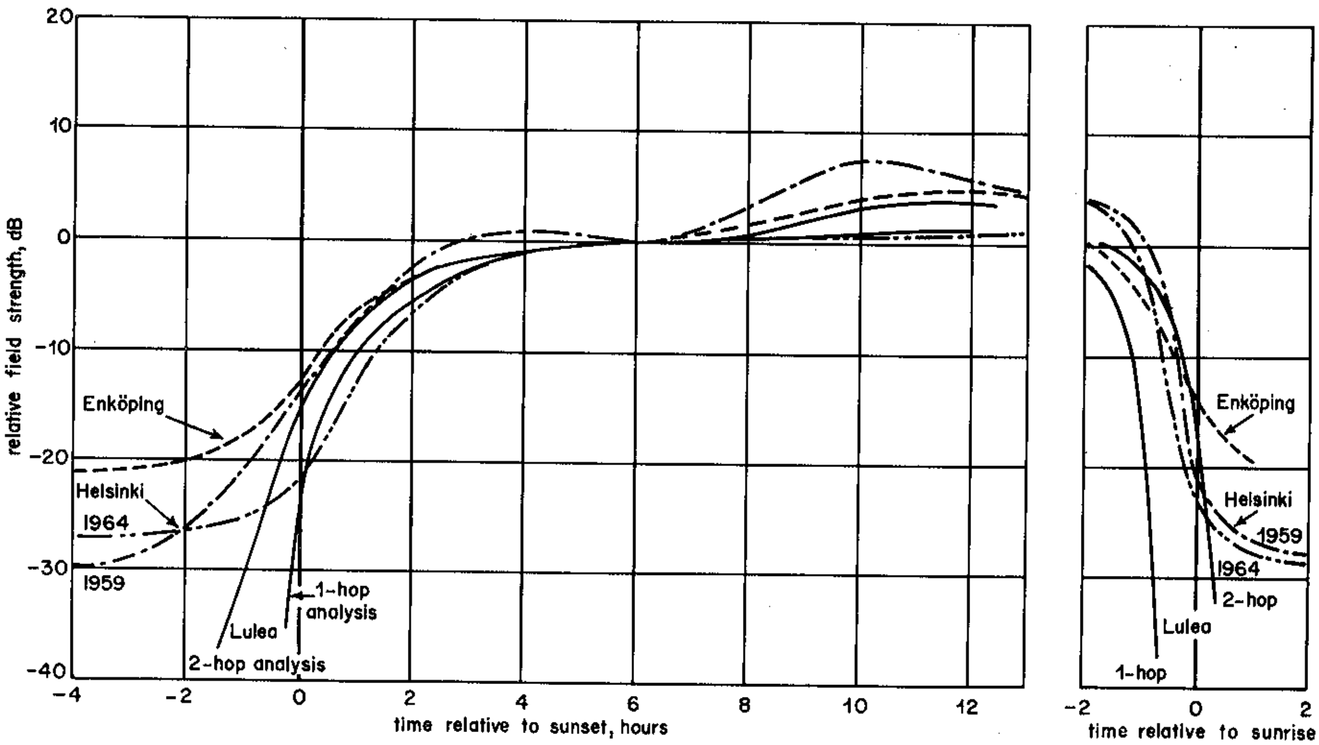

Fig. 2 - Comparison of median field strengths measured on three paths

All curves adjusted to coincide 6 hours after sunset

2.2. Allouis-Helsinki path (2060 km)

Measurements were made at Helsinki at fortnightly intervals during 1959 and were continued until 1965. The results for 1959 are similar to those obtained on the Enköping path.

Solar activity was high in 1959, which was near the peak of the solar cycle. Since earlier EBU measurements[2] had shown a relationship between solar activity and median field strength, the measurements made in 1964, when the sunspot number was low, were also analysed. The difference between the medians for the two years was found to be highly significant statistically between 3 and 8 hours after sunset, and again at 2 hours before sunrise, and is consistent with the result obtained by the EBU.[2] If the EBU correction for solar activity is applied to the two sets of medians, the period during which they differ significantly is greatly reduced.

2.3. Allouis-Lulea path (2350 km)

The maximum range for one-hop sky-wave propagation is 2100 km when a wave is projected tangentially and reflected from a height of 90 km. Single-hop propagation extends beyond this range at l.f., however, because waves are diffracted round the surface of the Earth. As the distance increases the 1-hop mode becomes severely attenuated by diffraction loss and the 2-hop mode then becomes the stronger.

The mode which predominates at sunset and sunrise controls the rise and fall of the sky-wave signal. On the paths already considered it is reasonable to assume that the 1-hop mode predominates but on the longer Allouis-Lulea path the two modes are likely to be of comparable strength. The total theoretical diffraction loss for the 1-hop mode is 35 dB, assuming ground of average conductivity (5×10^{-3} mhos/m) at both terminals.[4] This is offset by the greater ionospheric absorption of the 2-hop mode; the loss for the 2-hop mode may be almost double that for the 1-hop mode because the angles of incidence of the two modes at the ionosphere are similar. The difference between the ionospheric losses is difficult to estimate at sunset and sunrise and the relative importance of the two modes at this time is uncertain.

The measurements on the Allouis-Lulea path were analysed twice to determine whether 1-hop or 2-hop propagation predominates at sunset and sunrise. With 2-hop propagation, sunset and sunrise times generally differ at the two reflection points. The onset of night-time propagation is controlled by the point where sunset occurs latest, while the transition at dawn from night to day conditions is determined by the point where the sun rises first. On the Allouis-Lulea path, control of 2-hop propagation alternates between the two reflection points during the year.

3. Field-strength variation during the night

In Fig. 2 the median field strengths measured on the three paths are compared directly, the curves being arranged to coincide at 6 hours after sunset. Both of the analyses for the Allouis-Lulea path are included in the comparison.

The principal difference between the curves arises before sunset and after sunrise, when they are influenced by the ground wave. If this influence is disregarded, the 2-hop analysis of the Lulea measurements is seen to be more consistent with the other measurements than the 1-hop analysis, especially at sunrise. The comparison also suggests that the 1964 Helsinki measurements may have been influenced by 2-hop propagation at sunset, but the evidence is not conclusive.

Fig. 3 shows an average median curve derived from Fig. 2, the 1-hop analysis of the Lulea measurements being excluded. The effect of the ground wave has also been

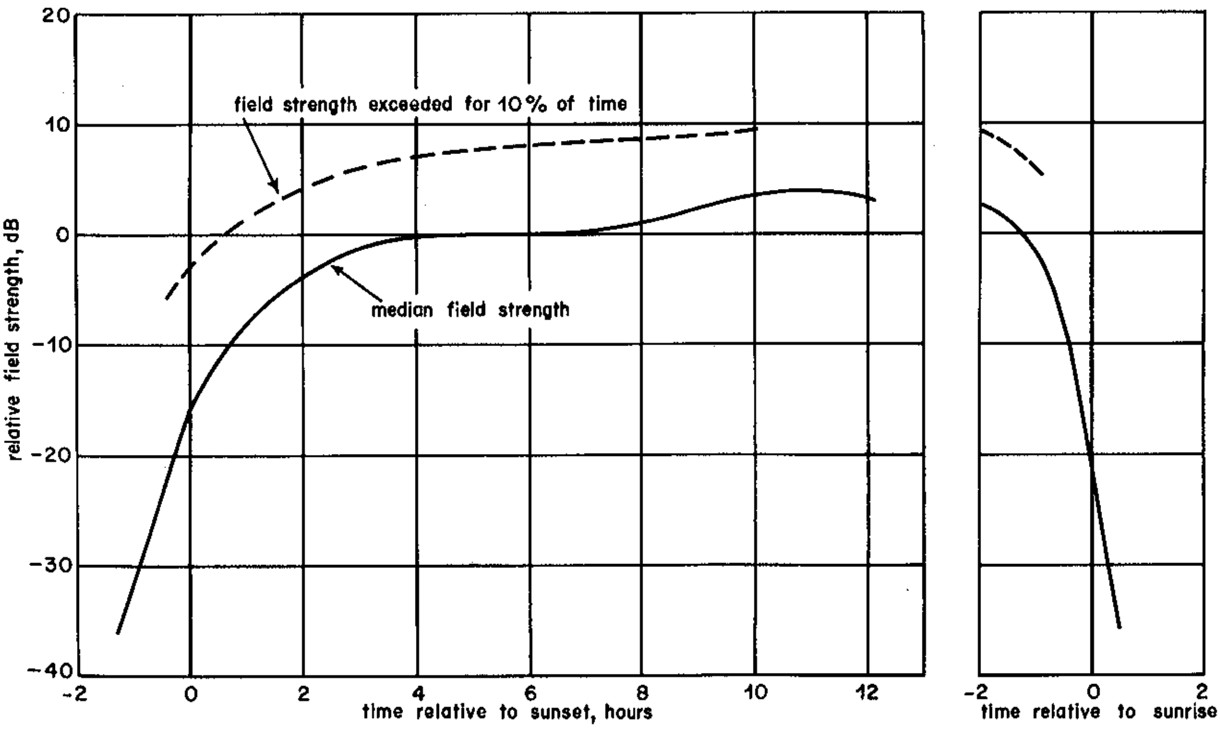

Fig. 3 - Field-strength variation during the night

The curves are referred to the median field strength 6 hours after sunset

disregarded. Thus Fig. 3 shows how the median sky-wave field strength varies on average during the night on paths of about 2000 km. Also shown in Fig. 3 is the variation of the quasi-maximum field strength during the night; the derivation of this curve is discussed in the next section.

4. Day-to-day and short-period field strength variations

During the night the quasi-maxima and quasi-minima tend to be symmetrically spaced above and below the median, indicating that the measured half-hourly medians (in decibels) are approximately normally distributed. Table 1 shows the ratios (in dB) of the quasi-maxima and medians of the half-hourly medians at various times during the night for the four sets of measurements.

TABLE 1

Ratios of quasi-maxima of half-hourly medians to median values of half-hourly medians (dB)

Time	Enköping	Helsinki 1959	Helsinki 1964	Lulea	Average
SS	11·5	12	12·5	12·5	12·1
SS + 3	7	6·5	5	7·5	6·5
SS + 6	7	8·5	5·5	9	7·5
SS + 9	4·5	5	6	8	5·9
SR − 2	8	7	2·5	7·5	6·1

SS = sunset SR = sunrise

The figures contained in Table 1 show how the quasi-maxima of the half-hourly medians vary from day to day but they do not indicate the absolute field strength variation because no account has been taken of variations occurring within the half-hour periods. In an earlier series of EBU measurements,[2] however, quasi-maximum to median ratios measured during one-hour periods were noted; variations occurring within half-hour periods would be similar. The absolute field strength variation may be estimated from the short-period and day-to-day variations; if both variations are assumed to be normally-distributed, the absolute quasi-maximum to median ratio is the r.m.s. sum of the individual ratios.

Although the earlier EBU measurements were made at a fixed hour shortly before midnight, results for various times relative to sunset may be derived from the measurements made at different times of the year. Table 2 contains quasi-maximum to median ratios measured at mid-summer, equinox and mid-winter over the three paths, each tabulated value being the average of ratios measured on about 20 nights selected at random. Table 2 shows that the short-period ratio does not vary greatly during the night; it has an average value of about 3 dB. This figure was used to calculate absolute quasi-maximum to median ratios from the average ratios contained in Table 1; the results are given in Table 3.

TABLE 2

Ratios of quasi-maxima to median values measured within one-hour periods (dB)

Time of year	Time after sunset (hrs)	Quasi-max/median ratios (dB) Enköping	Helsinki	Lulea
Summer	2	3·8	2·9	–
Equinox	4·5	2·9	2·2	3·3
Winter	7	2·1	3·3	3·0

TABLE 3

Absolute ratios of quasi-maxima to median field strengths (dB)

Time	Ratio
SS	12·5
SS + 3	7·2
SS + 6	8·1
SS + 9	6·6
SR − 2	6·8

SS = sunset SR = sunrise

Table 3 shows the extent to which the annual median field strength at specified hours relative to sunset or sunrise is exceeded for 10% of the time. The quasi-maximum curve of Fig. 3 was derived by adding the values contained in Table 3 to the median curve.

5. Absolute field strength

The reference time for the EBU/CCIR field-strength curves is midnight. Since midnight occurs, on average, 6 hours after sunset, it is of interest to compare median field strengths measured at this time with the midnight median values derived by the EBU. On the three paths considered here, the greatest difference between the two medians is 2 dB, the average difference being 0·5 dB. It is therefore reasonable to conclude that midnight medians, and medians for 6 hours after sunset, may be regarded as equivalent, at least for paths shorter than 2,500 km.

The EBU corrected the measured field strengths to take account of solar activity and magnetic dip latitude; details of the method of correction are contained in Reference 2. The solar activity correction compensates for the greater ionospheric absorption at the peak of the solar cycle and has a maximum value of 4 dB. The magnetic latitude correction takes account of the high absorption losses which occur in the auroral zone and may exceed 20 dB; although it was derived from measurements made at m.f. its application to l.f. appears to be justified. Fig. 4 shows corrected measurements* for 164 kHz together with

* Reference to detailed information contained in EBU committee paper Com.T(B) 43 (1961, unpublished) shows that the corrected value for Tel Aviv is apparently 4 dB too high.

a propagation curve for this frequency interpolated from the published EBU/CCIR curves. Measurements for distances less than about 1000 km are not shown, because they are influenced by the ground wave to differing extents.

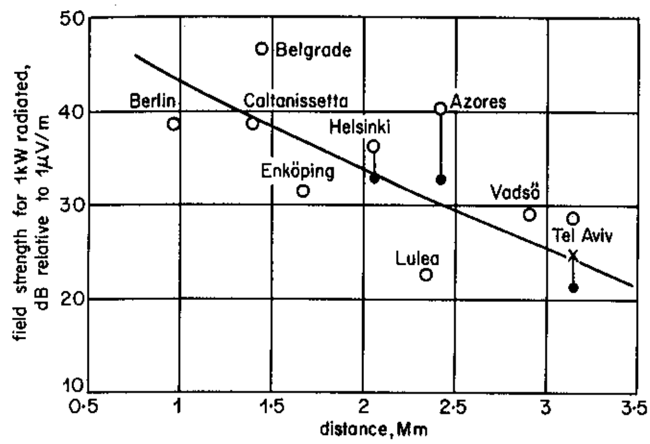

Fig. 4 - Absolute field strength

o Corrected midnight median values measured by the EBU
x Corrected value for Tel Aviv reduced by 4 dB (see footnote on page 4)
• Measured values adjusted to ground loss
— EBU/CCIR curve for 164 kHz

The measuring sites at Helsinki, the Azores and Tel Aviv are close to the sea. It has been shown[5] that proximity of a transmitter or a receiver to the sea increases the strength of m.f. sky-wave signals. At l.f. the effect is similar, but the influence of the sea may extend as far as 100 km inland. The signal strength is further increased on the 2-hop Allouis-Azores path because the intermediate reflection point falls on the sea. Fig. 4 also shows the field strengths which would have been measured at these three receiving points if the sea were replaced by ground of average conductivity (5×10^{-3} mhos/m). It will be seen that the scatter about the propagation curve has been reduced.

6. Conclusions

If the frequencies in the l.f. band are re-allocated at a future conference, co-channel transmitters are likely to be situated about 2000 km apart. At this distance, sky-wave propagation from a high-power transmitter will be sufficient to cause interference at night.

A re-analysis of the measurements made by the EBU has shown that the median sky-wave field strength 6 hours after sunset is approximately equal to the average value for midnight, given by the EBU/CCIR curves. At sunset the median field strength is about 15 dB less than the median value 6 hours later, and the rate of increase is about 10 dB per hour. At sunrise the median field strength is about 20 dB less than the value 6 hours after sunset, and the rate of decrease is about 25 dB per hour. The field strength exceeded for 10% of the time is about 12 dB greater than the median field strength at sunset, and about 7 dB greater than the median late at night.

At sunset and sunrise 1-hop propagation predominates to distances of about 2000 km. At greater distances the 2-hop mode is stronger. When the 2-hop mode predominates the transitions between day and night conditions are controlled by the reflection point where the sun sets latest and by the reflection point where the sun rises first.

Some of the measurements made by the EBU were enhanced by the presence of the sea. If these measurements are replaced by the values which would have been measured over land paths, the scatter about the propagation curves drawn by the EBU is found to be reduced. The EBU/CCIR l.f. curves may therefore be regarded as applying to paths whose terminals are well inland, with land at the intermediate reflection points (if any).

In estimating l.f. sky-wave field strengths for distances of about 2000 km it is recommended that median value for midnight be derived from the EBU/CCIR propagation curves. Corrections for transmitter power, aerial gain, sunspot number and magnetic latitude should then be applied in the manner recommended by the EBU/CCIR. A correction may also be added, if required, to allow for the influence of the sea. The corrected value may now be regarded as the median field strength for 6 hours after sunset. Median and quasi-maximum field strengths for other times may then be calculated by applying corrections derived from Fig. 3.

7. Acknowledgement

Thanks are due to the Technical Director of the EBU for providing a copy of the detailed results of the measuring campaigns.

8. References

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